THE ROAD TO MODERN SCIENCE

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By

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FOREWORD

THE primary object in writing this book was to present the story of scientific discovery in a form which would appeal to intelligent boys and girls. The subject-matter of the majority of the books on the history of science is, in the main, too difficult for such readers. On the other hand, in those books which tell only the story of the lives of a few great scientists, the broad view of scientific discovery, as a whole, tends to be obscured.

While the audience I have had in mind has, therefore, been youthful, I hope very much that this book may also appeal to more adult readers for whom the scientific achievements of this modern world have not lost all their wonder, and who may like to read the story of what went before.

I should like to thank Miss C. M. Waters, B.A., and Miss E. C. Underwood, B.A., for much helpful advice and criticism of the text.

ordinary man; and, secondly, that it should be possible to explain it in a relatively simple manner. Inevitably, more demands on the understanding have had to be made, but it is hoped that readers of all ages may find something of interest.

H. A. R.

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PART I

CHAPTER I

The Trail Begins

MANY trails have been blazed since man first made his appearance on earth some hundreds of thousand years ago. Some of these have petered out long ago; others have merged together into wide roads which have run through the centuries and are now the main thoroughfares of our modern life. The trail which we are going to follow in this book has become perhaps the widest and most important of all others during the last three centuries. I mean the great Highroad of Modern Science. The Road is still being made, wide and straight and filled with traffic. Some of the wise people who are watching its progress are asking 'Where will it lead—to a good end or to a bad?' That is a question that not only the makers but the users of the road must consider.

Now what really is Science? The word 'science' means 'knowledge,' so that in its broadest sense it means *all* the knowledge that man has gained, arranged in an orderly manner. Thus everything that is learnt in school is really Science. We generally use the word, however, with the more limited meaning of our knowledge and understanding of the world around us as it is shown to us through our various senses. Notice that knowledge can only be called 'science' when it is *orderly*. Man gained a great deal of knowledge before he began to think about it as 'knowledge'; that is, to arrange and

classify it, to notice similarities and differences between various parts and so to make 'general statements.'

Now imagine that you do not live in the twentieth century but far back in prehistoric times. You are really almost an animal, but you are not quite, because you have a better brain than an animal, one which has the power to 'reason,' though only in a very elementary fashion. You have also a much more definite memory than an animal. You probably live in a cave with a tribe of other prehistoric people like yourself and you have to hunt for your food and protect yourself from other animals. That is your main business in life. Now because you have a better memory and because you can reason things out a little, you make a rather better business of living than the animals. You gradually rely more and more on your brain and less on your physical powers in order to escape the big animals and to kill the others for food. You find, for instance, that you can make a weapon out of a flint at the end of a wooden pole, which can do more harm than your teeth or claws, and which, at the same time, can keep you more out of range of the animal you are fighting. So gradually you accumulate a great many bits of knowledge that are very useful to you in your business of living. But each bit is quite separate from every other bit, and you only think of it as applying to the particular circumstances in which you first learnt it.

Two of the most important things that happened to primitive man were his beginning to talk and his beginning to count. The latter probably happened very much later than the first, and it is with this event that our trail really begins. Let us try to imagine how it happened.

At first, a prehistoric man fishing for his family would

go on fishing until each of the, say, five of them had a fish; but he could not go down to the river and catch 'five fish' unless his family were there to be given them in turn, until each had one. Later he learnt to count 'five fishes' or 'five stones,' but saw no connection between the two. Finally, however, on one of his descendants this connection dawned, and he realised that one, two, three, five, etc., had a meaning apart from the fishes or stones to which they had always been attached. That man, whoever he may have been, was the first pioneer to start blazing the trail which was to wind, now clear, now faint, now broad and straight, now narrow and tortuous, till the great giants of the sixteenth century tracked their way through the undergrowth which had grown up and made our modern high road. As we look back upon the makers of the road we see that perhaps the most useful tool they had for their task was this knowledge of counting and number, which was first fashioned, crudely and roughly, by our unknown prehistoric man.

For many thousands of years man went on accumulating knowledge and using it for his business of living. He stopped living in small tribes and built himself cities and lived in large communities. In other words, he gradually became civilised. He still, however, only used his knowledge for the practical business of living and enjoying life. He had all sorts of luxuries; he learnt how to hand on his knowledge by writing; but everything he learnt or did had a practical end in view. He never found out things just for the sake of knowing them. The first people to pursue knowledge for its own sake were the Greeks, and with them 'Science' really has its origin. But in the efforts of the Greeks to bring all the

knowledge that man possessed into one big orderly whole, they had, to help them, all the knowledge gained by the men who had lived on the earth before their time. Thus, although it is only when we reach the Grecian Era that we find the signpost 'Science,' the trail is to be found if we look for it, winding from our prehistoric man through the time of the ancient civilisations to the foot of the signpost.

CHAPTER II

Through the Ancient World

THERE were three great races of people from whom the Greeks learnt their knowledge. They were the Egyptians, the Babylonians, and the Phœnicians; and they were all in a flourishing state during the years 1000 B.C. to 500 B.C., during which time the Greeks were gradually winning for themselves a strong position on the north-east coast and islands of the Mediterranean Sea. Let us see just what kind of a life these three nations lived at that time and what was the most important contribution of each to the knowledge which was the heritage of the Greeks.

The Egyptians.—The civilisation of the Egyptians is one of the oldest civilisations on the earth. These people lived on the banks of the Nile and the small strip of fertile country on either side. This fertile land they cultivated, and grew there a great many crops of much the same kind that we grow nowadays. Besides food-crops, they also grew flax, and, from the thread spun from this, they wove themselves linen garments and dyed them many beautiful colours from dyes which they learnt to make. They also grew the Papyrus grass, from which they made paper to write on, and thus left records of their doings which people living afterwards have found and read.

Now every year the Nile floods its banks because of the tropical rains which fall in the region where the river rises. This makes the land round it very fertile, but it also meant, at that time, that every year the fields on its banks had all their boundaries wiped out, so that the

land had all to be divided out again when the floods subsided. It was, therefore, very necessary for the Egyptians to have some way of measuring up the land, in order that after the flood each should have his right amount again. The land was measured out in rectangles, and a tax was paid to the King on each rectangle of a certain size. Now it was easy enough to measure the lengths of the sides of the rectangles, but it was not so easy to make the angles between the sides really right

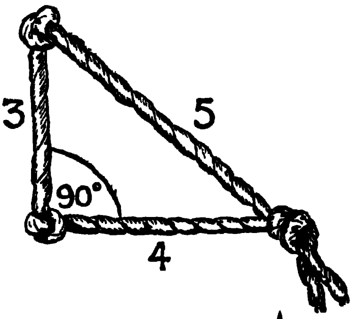

FIG. 1

angles. Remember that there were no protractors and geometry had never been heard of. However, the Egyptians discovered, practically, a very important bit of knowledge, which was, that if a rope of twelve units in length is divided by knots into sections of three, four, and five units and made into a triangle with the knots at the corners, then the angle opposite the side of five units is always a right angle. This is a special case of one of the theorems in geometry, but the Egyptians only knew it as a fact of experience, and, as far as we know, did not bother their heads as to 'why.' It was not until a long while later that a Greek, named Pythagoras, whom we

shall talk about again, realised that other lengths for the sections would also give a right angle provided that the lengths are related to each other in the special manner demonstrated in Pythagoras' theorem. Pythagoras was a *scientist*, but the Egyptian 'rope-stretchers,' as the land-measurers were called, were not.

The buildings of the Egyptians also show that they had great skill in practical measurement and construction, and their 'right-angle device' was used in building and orientating their temples. The most famous of their buildings were the great Pyramids or tombs in which they buried their kings. The fact that they have lasted about four thousand years shows how well they must have been built. These Pyramids, when measured to-day, are found to be very accurately constructed. The angles at the base are all almost exactly 52°. The Egyptians, of course, had no machines, and yet they were able to lift the great masses of stone of which the Pyramids were made to a height of 500 ft., higher than the cross on top of St Paul's Cathedral. This they did by means of ropes, pulled by a great army of slaves, and possibly by the aid of levers; but you must realise that they knew nothing about the 'lever law' which was discovered much later by another Greek, Archimedes.

One of the things which the Egyptians were the first to do was to invent a calendar. The earliest known date in human history is 4241 B.C., when the Egyptian calendar was invented. The man who devised this calendar knew that the sun took three hundred and sixty-five days to complete the circle of the seasons; and that the moon went round the earth in twenty-eight days. This shows that the Egyptians must have watched the movements of the sun and moon very carefully. Their

records also tell us that they watched the stars as well, calling certain of them by definite names and picking out groups of them which seemed to form pictures. These are what we now call the constellations, and our names for them mean the same as did the old Egyptian names.

The Egyptians did not just stay quietly in their lands on the banks of the Nile. They built themselves ships, and in these they ventured down the Nile into the Mediterranean; and, by cutting the first Suez Canal, they sailed through to the Red Sea. In this way they traded with, sometimes conquered, other civilised nations, and later on were in their turn conquered. So they obtained more knowledge, not by discovery for themselves, but by copying what they saw being done by those other nations.

The Babylonians.—The chief race of people with whom the Egyptians came in contact were the Babylonians who inhabited the land between the rivers Euphrates and Tigris, which is now called Iraq. In most ways the civilisation of the people dwelling in Mesopotamia was very much the same as that of the Egyptians. They cultivated the land; wove and embroidered their clothes; built themselves cities and palaces; and made laws which they wrote down, so that we find them to-day.

Babylonia was not quite so fertile a land as Egypt, nor was the climate quite so good. To water the land away from the river they therefore built canals, and so were the first people to use irrigation. Again, unlike the Egyptians, they had not great quantities of building stone in their land. Instead, they made bricks out of clay and baked them in the summer sun. These bricks were not as lasting as stone, and so we do not find their buildings still standing entire to-day.

They also used clay to make tablets on which to write. They probably began by picture writing, using a reed to mark the clay; but this did not make good pictures, so that they soon took to using symbols, something like this Y—<. Whole libraries of these tablets have been found, and these tell us a great deal about the life of the Babylonians. They were quite good at counting, and at arithmetic, but they did not usually count in tens, as we do, but in sixties. Thus, suppose that (in their writing) they wrote a number such as 16; the 1 would not stand for ten but for sixty, and the number would therefore be sixty-six not sixteen. Our division of the hour into sixty minutes, and the minute into sixty seconds, dates right back to the days of Babylon.

Amongst the things which have been dug out of the ground in the land of the Babylonians are a number of very beautifully worked chains and vessels in gold, silver, and bronze. We know, therefore, that they must have had very skilled metal-workers amongst them. Now the discovery of metals, and of how to use them for making weapons and vessels, was one of the most important discoveries in the history of man. At first, as you know, man made himself weapons of flint and stone. Copper was probably discovered by the Egyptians first. Perhaps some Egyptian traveller on the Sinai peninsula made a fire and built it round with bits of rock which he found lying about. In the morning, when he raked out the fire, he found among the ashes hard shiny, red beads of copper. What had happened? Nowadays, we get a very great number of metals out of the ground and use them for all sorts of purposes, but only a very few of them look like metals when they are in the ground. Before they can be used, the rocks containing them have to be

treated in some way, and nearly always, at some stage, they have to be heated with carbon either as coke or charcoal. This process is known as smelting. Now you will see how that old Egyptian got his copper. The hot charcoal from his fire acted on the rocks surrounding it and produced the metal copper. At first he probably only used these metal beads as ornaments, but when he discovered how hard they were he would try to get more with which to make weapons or vessels.

Now copper melts at a considerably lower temperature than a metal such as iron, and so it was quite easy to melt the copper and so to make it into any shape that was wanted. It can also be won from the rock containing it, at a much lower temperature than iron, and that is probably why it was discovered so long before. Gold, silver, and tin were discovered somewhere about the same time as copper, but gold and silver are too soft to be of very much use by themselves for anything but ornament. A method of hardening copper still further was discovered when the metal had been in use sometime under a thousand years. This was done by melting a little tin with the copper and making the alloy known as bronze. For very many years this was the hardest and strongest substance known, and all weapons were made of it. From the many articles of bronze, copper, gold, and silver that have been found in Babylonia, it is clear that the old inhabitants of that country must have been greatly skilled in all kinds of metal work.

The thing for which the Babylonians are most famous is their study of the stars. They seemed to have noticed that things on earth began to grow when the sun, at midday, was a certain height in the sky. They saw, also, other changes on the earth, and noticed changes in the moon

and stars occurring at the same time. From this the idea grew up that the sun, moon, and stars really controlled the happenings on earth. It therefore seemed to them very important to study the changes in these heavenly bodies, so that they might glean from them some information as to what was likely to happen on earth. Accordingly, their wisest men spent their lives in watching the sky, recording all changes and making star-maps. The magi of the Bible were probably three of these wise men of Babylonia. Notice that they did not study the stars just for the sake of knowing about them, but because they thought that from their changes they could foretell future events on the earth. These men were what are known as Astrologers, while the men of to-day who study the stars, for the sake of knowledge alone, are called Astronomers. Nevertheless, the records of these old Babylonian astrologers have been very useful to later astronomers, because most of the changes in the sky are very slow, and so it is of great value to have records of what the sky looked like thousands of years ago.

The Babylonian astrologers picked out the five planets: Mercury, Venus, Mars, Jupiter, and Saturn; and these five 'wandering stars,' with the sun and the moon, were supposed to play an extremely important part in the lives of men. Like the Egyptians, they had also names for various constellations or groups of stars. Now, each day the sun at noon occupies a slightly different position among the stars, and during the year it apparently traces out a huge circle in the heavens. The constellations which lie on this circle were supposed to be of especial importance, and the representations of them are still known as the signs of the Zodiac.

From their observations of the sun in its course across

the sky, the Babylonians made the first clock. It was known as a water-clock or clepsydra. They allowed water to drip regularly from a large vessel, and the moment the sun's upper rim began to appear above the horizon

Fig. 2

they began to collect it. Directly the whole of the sun was above the horizon they changed the vessel and went on collecting until the sun just began to appear above the horizon next day. By dividing the water into equal parts they thus had a means of dividing the day into equal parts and so first began to reckon time.

The Phœnicians.—At the time of the rise of Greece the Phœnicians were the great traders of the world. They were only a small nation, and from some points of view

might not be considered so worthy of mention as other small nations existing at that time. It is because of the great part they played in spreading knowledge that they must be mentioned here.

The Phœnicians lived on the narrow fertile strip on the west of Asia Minor, just north of Palestine. In their country were the famous cedars of Lebanon, and from these trees they built themselves ships and traded all round the Mediterranean, even through the Straits of Gibraltar and round the coast of Spain as far as Cornwall. On the mountains behind their coast they reared sheep, and from the wool wove cloth. They were especially clever at making dyes and with these they dyed the cloth they wove.

The important discovery of how to make glass is sometimes attributed to the Phœnicians. They certainly knew how to make it and traded in it with the countries they visited. The story goes that some Phœnician sailors making a fire on a sandy shore, built the fire round with bits of stone which probably contained lime and natron (soda). On raking the ashes they found not copper this time, but glass; for lime, soda, and sand are what we now use to make glass. As a matter of fact, glass was probably made for the first time long before the time of the Phœnicians, but that is very likely the way in which it was first made.

The Phœnicians also became very expert metal-workers, and this was perhaps the basis of their most important trade with the more uncivilised parts of western Europe. They guarded the secret of their skill very jealously, however, and would only hand on the lore to their own race. Many of them settled in different parts of Europe and became the smiths of the countryside. Cornwall,

being so rich in mineral wealth, soon had a Phœnician smith to almost every tribe, and to-day, if you go to Cornwall, you may meet people who proudly claim to be descended from the Phœnicians.

. . . .

Let us now take a wide view at the world about 1000 B.C. and during the next few centuries. Asia was the centre of civilisation. Almost all of the southern part of that continent [1] was inhabited by civilised people—that is, by people who had, to a great extent, learnt how to control the natural world around them and to live a life in which there was room for leisure. There was intercourse of trade and war between the various nations, and in both ways knowledge was spread amongst the peoples. But everywhere we see this knowledge being applied to practical purposes and being valued only for the part it played in contributing to the safety and comfort of man. As more knowledge was accumulated, so the people grew in luxury and wealth. But no new ground was broken, and superstition prevented any step forward. These were not the people who were to strike out into the unknown and blaze new trails in search of greater things.

[1] India and China are not especially mentioned here—not because they were not important centres of civilisation at that time, but because the paths of knowledge made by them never joined up with the path which eventually led to our modern high road of science.

CHAPTER III

Into a New World

We have already seen that copper was discovered and used a long time before iron. The discovery of the latter and of how to weld it into weapons happened somewhere about 1200 B.C. About this time a new race of people settled on the shores of the Ægean Sea in the land known to them as Hellas, but to us now as Greece. It has been suggested that these people were greatly helped in the conquest of the inhabitants of that country by the use of weapons made of the new metal, iron. Whether or not the Greeks did thus truly usher in the 'Iron Age,' it is quite certain that they brought to the civilisation round the Mediterranean Sea a new age of the mind—the Age of Science, of the desire to understand and to explain everything that they saw happening round about them.

Until about 700 B.C. the Hellenes were occupied in establishing themselves in the land, and fighting, one state with another. By this date, however, a number of prosperous city states had been established, and most of the islands in the Ægean Sea had been colonised. Of these island colonists the Ionians are particularly famous, and to them belonged Thales, the first of the long line of Greek philosophers or 'seekers after the ultimate truth.'

Thales.—Thales was born in Miletus in 624 B.C. Like many of his countrymen he was originally a prosperous merchant and traded chiefly in salt and oil. In this way his business took him abroad a great deal, and especially to Egypt. Now while in that country he became very

much interested in the practical knowledge of the Egyptians, more especially in their methods of land measurement, and in their observations of the stars. He therefore collected as much information as he could, and when he got home he gave up his business as a merchant and devoted the rest of his life to 'philosophy.' One of the first things he realised about the Egyptian rules for land measurement was that they were only special cases of much more general rules. These 'general rules' which he stated were the true beginnings of the science of geometry. One particular theorem which Thales stated and proved was the one about angles at the base of an isosceles triangle always being equal. Once started on geometry the Greeks took to it like ducks to water, and there is very little of the geometry learnt at school which did not originate from them.

Another interesting thing to note about Thales is that, as far as we know, he was responsible for the very beginning of our knowledge of electricity. He found that when amber is rubbed it can attract small light things to it, or, as we now say, it becomes electrified. Now the Greek word for amber is 'electron,' and so all our words of that root can be traced back to Thales and his experiments with amber. He also possessed a bit of lodestone, which is a naturally occurring magnet, and he found out many of its properties.

Perhaps the most important thing of all to remember about Thales is that he was one of the very first men to ask the question: 'What is everything made of?' This question was, perhaps, more discussed than any other by Greek philosophers. Although a variety of answers were given, it was fairly unanimously agreed that the different things found round about them were made

up from just a few simple substances which were called 'elements.' Thales himself said that all things were originally produced from water. Now, it is very interesting to note that, at the present time, scientists have come back to the old Greek idea that all matter has evolved from one single substance. This substance is not, however, water as Thales believed, but hydrogen.

Thales, as well as studying philosophy, on his own account, also taught his conclusions to others. Some of these themselves made important contributions to the knowledge of their day, and in their turn had pupils of their own. In this way the love of philosophy spread, and everywhere through Greece we find men questioning and seeking explanations of all that they saw about them. Here, indeed, was a race of road-makers, continually breaking fresh ground and pressing on into the unknown. We can only mention one or two of the most famous of the Greek philosophers, and only those who were most interested in what we now call Science. The next one we shall take is one whom we have already mentioned, namely, Pythagoras.

Pythagoras.—Pythagoras was also an Ionian and was born in the island of Samos in 580 B.C. Like Thales he travelled to Egypt and also perhaps to Babylon, and thus became familiar with the ways of the people of those lands. On his return he settled in southern Italy, which by that time had become a Greek colony. Here he became famous. Many people came to learn from him and a kind of brotherhood was formed. Before joining the brotherhood everyone had to take certain vows, some of which were definitely religious. All vowed to live a simple and austere life. It is interesting to find that women were

admitted to this brotherhood, and the wife of Pythagoras was an important member.

We, however, are only concerned with the contributions of Pythagoras to Science. We have already attributed the beginning of geometry to Thales, but Pythagoras is definitely the founder of the Science of mathematics as a whole. He was more interested in 'numbers' than in anything else, and he thought that the numbers connected with any object were the most essential part of it. 'Ten' he called the perfect number, because $10=1+2+3+4$. 'Three' was the sacred number; it was the number of the universe, because everything has its beginning, its middle, and its end. If you think of the well-known theorem of Pythagoras you will remember that it is the theorem where numbers play the most important part. Since he was so fond of numbers you will not be surprised to hear that Pythagoras first introduced a proper system of weights and measures.

The study of the theory of sound was first begun by Pythagoras. The story goes that one day, while passing a blacksmith's shop, he was attracted by the musical notes emitted by the anvil on being struck by the hammer. This led him to investigate the notes produced by strings of various lengths and thickness, and he found that if he had two similar strings, but one twice as long as the other, the short one produced a note which was an octave higher than the other. If the ratio of the lengths was 3 : 2 the interval was a fifth, while with lengths of 4 : 3 a fourth was produced. Again he got back to his magical series one, two, three, four, and the idea of harmony and proportion in everything. Following up the same idea, he pictured the universe as having a central fire around which the sun, the earth, and the planets revolved with varying speeds,

each creating its own celestial note, according to its distance from the central fire, and all together giving rise to the 'music of the spheres.'

Like Thales, Pythagoras sought an answer to the question of the structure of matter. He, however, held the theory that all matter was made, in varying proportions of four elements—earth, air, fire, and water. This is known as the famous 'four element' theory which held sway until the end of the Middle Ages. The teachings of Pythagoras had more influence than those of Thales, and, in fact, were only eclipsed by those of the great Aristotle himself.

Hippocrates of Cos.—Before we come to Aristotle there is one other Greek philosopher whom we must mention. This is Hippocrates, known as the 'Father of Medicine.' He was born in the island of Cos in 460 B.C. Like Thales and Pythagoras he travelled extensively over the countries bordering the eastern Mediterranean.

Up to this time, if a man were ill it was thought to be an infliction of the Gods, and that the only remedy was to appease them by offering sacrifices. Thus the chief people concerned in the healing of sickness were the priests of the temples. Now, Hippocrates taught that sickness was due to something wrong in the working of the body, and not to an external cause such as the displeasure of the Gods. To be able to cure the disease, he said, one must study the patient and find out what is causing the trouble. This, of course, is just what doctors of to-day try to do. Hippocrates' theory was that there were in the body four humours or juices—blood, phlegm, yellow bile, and black bile. When these were present in the right proportions and properly mixed, then the body was healthy; but if the proportions were incorrect, then

illness resulted. Now, although this is now known not to be the true explanation, it was the one held by all doctors until about four hundred years ago, and it certainly was nearer the truth than the supernatural one believed up till then.

Hippocrates was the first to propound what is, nowadays, a very favourite maxim: 'Nature is the best of all healers'; and his chief method of cure was a regulation of diet. So Hippocrates thus well deserved the title 'Father of Medicine,' and it is most interesting to know that the oath which was taken by his pupils before they were allowed to practise medicine is still taken in much the same form by medical students to-day who are about to become doctors.

CHAPTER IV

Aristotle

WE now come to the two greatest names among all the Greek Philosophers, Plato and his pupil Aristotle. Plato himself was a pupil of another, the famous Socrates, of whom you have probably heard; and Aristotle, in his turn, was tutor to Alexander the Great. So we have a chain of four great personalities linked together; and the interesting thing is that they are all quite different. From the point of view of science, Aristotle is far the most important of the four.

Plato.—Plato, who lived between the years 427 and 347 B.C., founded a very famous school in Athens known as the Academy. It stood in a pleasant grove with shady walks, and over the door was written the inscription: 'Let no one ignorant of Geometry enter here.' This would lead you to think that Plato must have been a true follower of Pythagoras, but this was not the case; for he thought that to apply geometry to practical purposes, such as making instruments, was degrading it. Geometry, he said, was a means of withdrawing the mind from material things and concentrating them on the abstract. Thinking, in this way, on geometrical figures he came to the conclusion that the circle was the most perfect curve in nature, and that therefore the paths of the various heavenly bodies must be in circles. Now, Plato was such a great man that his teachings were implicitly believed, not only by all the Greeks who lived after him but by all the people of western Europe for many hundreds of years.

So that, when a man named Kepler, who was a friend of Galileo, nearly two thousand years later, showed by observation and calculation that most of the planets did not travel in circles but ellipses, very few people, at the time, were disposed to believe him.

Plato was not really very much interested in the natural world about him. He was far more interested in Man and in the way in which he ought to behave; or, to use the proper word, he was interested in Ethics. His use for geometry was, therefore, to teach his students to think clearly and reason logically.

Aristotle.—To Plato's Academy, when he was eighteen years old, came an enthusiastic, energetic young man named Aristotle. Aristotle was born in Stagira in 384 B.C. and was the son of a physician. He had, therefore, been brought up amid circumstances which had created an interest in medicine and biology, and this persisted even when under such different influences as at the Academy. He worked so hard that he quickly became one of Plato's best pupils. He is said to have reduced the hours spent in sleep to a minimum. When he was reading in bed at night he placed beside him a brass basin, over which he held in his hand a leaden weight. When he was overcome with sleep, the weight dropped from his inert hand and the sound of its fall into the basin awakened him. It is not altogether surprising that a man of such persistent and untiring energy should have exercised such an influence over the thoughts of mankind for so many hundreds of years.

Aristotle stayed at the Academy until Plato died in 347 B.C. He then left Athens and shortly afterwards became tutor to the young Prince Alexander, son of King Philip of Macedonia. When Alexander became king

Aristotle returned to Athens and started a school of his own, which was called the Lyceum. At the entrance to the building was a covered portico or 'peripatos,' from which led a gravel walk between an avenue of trees. Here Aristotle used to walk up and down with his pupils, discussing various problems and teaching as he went. Because of this, his school became known as the Peripatetic school, and his followers were known as the Peripatetic philosophers.

It was at this famous school that, during the next twelve years, Aristotle gave himself up entirely to what he considered his 'life-work.' This, very briefly, was to write a catalogue or compendium of the knowledge of all natural phenomena. Up till then the various great men who had found out things and taught their knowledge to others had done so chiefly by word of mouth, and only fragments of their teachings had been preserved in writing. It is, of course, chiefly because of the fact that Aristotle wrote down so much that his teachings had so much influence for such a long time.

Aristotle's method of setting about things was this: First of all, he collected as many 'facts' as he could about every kind of subject he could think of—animals, fishes, plants; moving bodies; different kinds of matter; the phenomena of burning; the stars and heavenly bodies, and so on and so forth. Then he classified them into groups and under various heads; and finally he made theories as to why things happened as they did and were as he found them, reasoning always about things in the proper logical way which he had learned from Plato.

All this sounds very excellent, and yet Aristotle was one of the greatest stumbling-blocks in the way of later great scientists such as Galileo. How did this come to be so?

The fault lies not so much with Aristotle as with the scholars of the Middle Ages who, as we shall see, paid him such deference that they would not admit that he could be wrong. Their attitude was the real enemy to scientific progress in the fifteenth and sixteenth centuries. Aristotle relied on general observation to establish his facts but did not test these facts by experiment. So, when these facts were wrong, incorrect conclusions were drawn. This applies to nearly all his teachings in the branch of Science which we now call Physics; and since it was in Physics that the great advance was first made in the sixteenth century, once this new Science had firmly won its place, Aristotle and his teachings became very much discredited.

His answers to the two great questions of the time were also very far from the truth, but because they were Aristotle's answers they were implicitly believed until finally disproved in modern times. As to the constitution of matter, Aristotle taught, like Pythagoras, that there were four elements—earth, air, fire, and water. Each element also was supposed to possess two out of four primary qualities—heat, cold, moisture, and dryness. Thus earth was cold and dry; water was cold and moist; air was hot and moist; and fire was hot and dry.

Aristotle's idea of the universe was that the earth was fixed at the centre, and round it the moon, the sun, the planets, and the fixed stars revolved on separate spheres. So firmly did people believe that this view of the universe was the correct one that it almost became part of their religion, and hundreds of years later men who believed that Aristotle was wrong were persecuted and imprisoned for saying so, and one man was even burnt to death.

But there is one branch of science in which the work of Aristotle can win nothing but praise, that is in Biology.

PLATE I

Paracelsus

Archimedes

Plate II

An Alchemist at Work

Before he became tutor to Alexander he spent two years on an island in the Mediterranean, watching and studying animal life, especially fish. The results of this careful study he wrote down in books which have come down to us, and later added observations made with the help of the students of the Lyceum. The books about animals are the only ones which have reached us, though probably he also wrote about plants. Biologists of to-day are still amazed at the wonderful accuracy with which Aristotle described the life and habits of the creatures he watched. He also studied, by dissection, the structure of their bodies, and by examining eggs at various stages of incubation was able to trace the development of the chick inside the egg.

In all Aristotle is said to have written between twenty and thirty books on various subjects, although quite likely much of what is said to have been written by him was really written by others.

Now let us consider just what of good service Aristotle did for Science, and what of bad. His greatest contribution was unquestionably that spirit of eager curiosity and of inquiry which he brought to bear on every subject he investigated. That is the spirit which is to be found in every great scientist. His great dis-service was in stating so many things as facts, without first putting them to the test of experiment. Unfortunately his followers, especially those mediæval Christian monks who wove his teaching in with the teachings of their Church, thus giving them double authority, accepted blindly and unquestioningly his writings and ignored, or perhaps never even glimpsed, the man himself—the eager, curious seeker after truth. It was these men who were the true enemies of science.

Aristotle, then, built a great new stretch of the road of science. He made it wide and many travelled after him. The goal was clear in front of him, but he did not choose the right route, over the firm practical foundation of experiment. Thus, although the way looked straight and clear, the foundations of the road were faulty, and men coming after him sank and were lost in the mire of superstition and hearsay; or struck aside in search of will-o'-the-wisps that beckoned them astray.

CHAPTER V

Science in Alexandria

THE way now leaves Greece and again runs, for the next five hundred years, through Egypt. But the road-makers are still for the most part Greek by birth.

While Aristotle was teaching at the Lyceum in Athens, Alexander the Great was busy carrying out his conquest of the eastern peoples of Mesopotamia and Persia and of Egypt. In the last named, on the delta of the Nile, he founded the great city of Alexandria, which rapidly became a most important centre of trade and commerce. On the death of Alexander, his great empire was divided amongst his generals, and Egypt fell to Ptolemy, who was the wisest and ablest of them all. Under him—and, later, his son after him—Alexandria continued to flourish and became one of the most important cities of the world.

Ptolemy, besides being a great general, was also a learned man and liked to have always about him a group of philosophers and men of science. The rest of the empire, at that time, was in a very unsettled state, and so philosophers from all parts were only too glad to come to Alexandria and live peaceably under the patronage of Ptolemy.

After the death of Ptolemy his son determined to erect a building where all these philosophers could carry on their work and teach the young men that came in a continual stream to learn from them. Accordingly, the great Museum (or Home of the Muses) of Alexandria, was built,

and for the next seven hundred years this was the great centre of learning of all the civilised world.

The Museum was a very fine and beautiful building standing amid lovely gardens in which were shrubberies, flower-beds, fountains, statues, and alcoves. The building itself contained rooms of all sorts for study and recreation, but the most important of all was its great library. As many as possible of Aristotle's manuscripts were stored here and as much of Greek literature as could be procured. It is said that one of the rulers of Alexandria made a law that any notable man visiting the city must leave behind him a copy of any book he might have in his possession. So in one way and another books were collected until finally the great library is said to have contained seven hundred thousand volumes.

Alexandria thus took the place of Athens as the centre of learning and philosophy; and not only Greeks but, later on, the Romans came to Alexandria to be educated, just as, in the Middle Ages, from all over Europe young men went to the universities of Italy and to Paris; or, in our country, to Oxford and Cambridge.

At first the teaching was much the same as it had been at the Lyceum and the Academy, and Aristotle and Plato were names greatly revered by all. Gradually, however, a more practical side crept into the teaching. You will remember that the Greeks of Athens despised practical things and tried to make their teaching and thought as abstract as possible.

In Alexandria, however, there was constant contact with the natives of the country, the Egyptians and the Arabs. These, as you know, were intensely practical people, and undoubtedly influenced the Greeks living amongst them. So, instead of studying pure mathematics

and geometry alone, without relation to any definite, concrete matter, we find them studying mechanics—that is, mathematics applied to practical things such as the invention of machines.

Of the many hundreds of learned men who studied at Alexandria we can only mention *three* of the most outstanding.

Euclid.—Euclid was probably one of the first to come over to Egypt and settle in Alexandria. We know very little about the man himself, except that he lived somewhere about 300 B.C. and was possibly a pupil of Aristotle. His great book of Geometry, however, is known to all, though possibly not as bearing his name. Thirty or forty years ago the study of this subject was invariably known as 'Euclid'; and an English translation of the original work the only text-book used in this country. This book was really a collection of all the theorems in Geometry already produced by many Greeks before his time—Thales, Pythagoras, and many others—with some original ones of his own. It was the first time that they had all been collected together and arranged in order. No other book of Geometry was used to any extent for two thousand years.

Archimedes.—Probably you already know a good deal about Archimedes. He was born at Syracuse in Sicily in 287 B.C. He almost certainly went to Alexandria to study and therefore, although most of his life was spent in Sicily, he is rightly counted among the 'Wise Men of Alexandria.' When he returned to Syracuse he devoted the rest of his life to study, experiment, and research. Notice that I said *experiment.* As a scientist he was far superior to Aristotle, although his work was far less well known until after the time of Galileo.

Archimedes was really the founder of the science of mechanics. He was an engineer and an inventor. He it was who first discovered the 'Law of the Lever,' and this he applied to the making of all sorts of practical contrivances. The most famous story of his bringing his ingenuity to bear upon a practical problem is, of course, that about Hiero and his crown.

Hiero was the King of Sicily when Archimedes lived there, and at one time he had a new crown made for him out of a certain lump of gold, which he supplied to the goldsmith. For some reason or other he suspected the goldsmith of stealing some of the gold and substituting silver in its place. The crown weighed the same as the original lump of gold, of course; and pure gold is not very different in appearance from gold mixed with a little silver; so that the King could not tell from looking at the crown whether his suspicions were right. He therefore sent for Archimedes, who had made a reputation already as being a very wise man, and asked him to try to find out whether the goldsmith really had stolen any gold.

Now Archimedes knew that silver, bulk for bulk, was lighter than gold; so that if some silver were mixed with the gold in the crown, the latter would be slightly more bulky than if it were made from pure gold. What puzzled Archimedes at first was how to find out just what was the volume of the crown, because it was, of course, not made in the shape of a nice regular cube, or other geometrical body, which he could measure up. He was probably thinking over this problem when, one day, he went to the public baths. The vessel in which he took his bath was quite full, so that when he got in some of the water overflowed. Suddenly it dawned upon him that just in proportion as his body was immersed so the water

overflowed; and if the water overflowing were collected then he could measure the volume of his body in the water. Here, then, was a way of finding the volume of the crown. In great excitement he jumped from the bath and rushed home without waiting to dress, crying, 'Heureka! Heureka!' 'I have found it! I have found it!'

He had next to find a lump of gold and a lump of silver, each of the same weight as the crown, and to discover what was the volume of each and of the crown by his new method. The crown he found to have a volume larger than the gold but smaller than the silver. So the goldsmith was guilty!

Yet, in spite of all the practical problems to which he gave his attention, Archimedes' chief interest lay in abstruse mathematical problems, having no bearing on the everyday needs of life. He was, indeed, a true Greek.

In 212 B.C. Syracuse was attacked by the Romans, and Archimedes devised war-machines and other contrivances with which to repel the besiegers. The enemy, however, entered and took the city. Archimedes was found absorbed in one of his mathematical problems, of which he had made a diagram on the sand. On the approach of some Roman soldiers he called out to them not to spoil his circle. This so angered one of the soldiers that he promptly drew his sword and killed Archimedes, not knowing who he was. The Roman general, however, was angry at the news, for he had heard of his reputation as a great man of learning. He caused Archimedes to be buried with honour, and had a mathematical diagram engraved on his tomb.

Ptolemy.—After Archimedes, there is no great name

worthy of mention for more than three hundred years, until we come to Ptolemy, the great astronomer and map-maker.

He was by birth an Egyptian, and studied at Alexandria. He is chiefly known because he wrote a very important book called the *Almagest*, which means the Great System; and this book was the standard work on Astronomy for many centuries. In this book he collected together the works of all the early Greeks and added very many observations of his own. He then set out to explain all these observations in the light of Aristotle's teaching of the nature of the universe. This was, you will remember, that the earth is a fixed and immovable sphere at the centre of the universe and that round it the other heavenly bodies travel in circles. The reasons that Ptolemy gave in support of this theory seemed very satisfactory at that time. The earth was said to be a sphere because, during an eclipse, it cast a circular shadow on the moon. This, of course, was perfectly correct. Next, the earth was said to be immovable, because, were it moving, everything on it, but not absolutely fixed to it, could not remain there, since heavy bodies travel more quickly than lighter ones. The lighter bodies on the earth would therefore get left behind. This, of course, is a very sensible argument, but unfortunately based on a wrong assumption about moving bodies, as we have seen. Lastly, it was said that the movements of the heavenly bodies must be perfect, and therefore must be in circles; for Plato had said that these were the perfect curves. Unfortunately, Ptolemy's observations showed him that the planets did *not* move in simple circles round the earth. He, however, very ingeniously invented a way in which he could make the

planets move in circles and still occupy their observed positions in the sky. He did this by supposing them to move in epicycles! That means that each planet kept moving in a circle round a definite point; but the point did not keep still but moved continuously in a circle round the earth. The diagram, fig. 3, should make this clear. Of course, it is not at all what the planets really

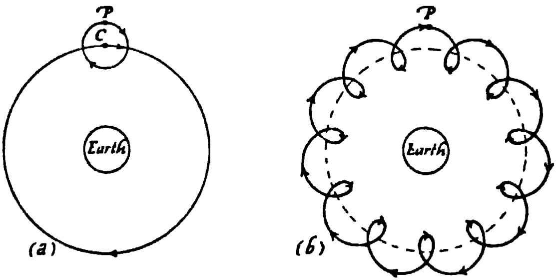

FIG. 3.—(*a*) the planet P moves in a circle round a point C which moves in a circle round the earth. (*b*) Shows the apparent path of the planet round the earth

do, but it saved Aristotle's reputation for quite a long time.

Besides being an astronomer, Ptolemy was also a great geographer. He wrote another book, which was used for many hundreds of years, and which contained maps of all the known parts of the world, including India, China, and even Norway. These maps all contained lines of latitude and longitude.

Apart from Archimedes, it cannot be claimed that the Greeks of Alexandria did much to extend the already existing road of Science. What they did was to keep clear and make known the road of Aristotle and others of the Golden Age of Athens. Archimedes, on the other

hand, struck out for himself, a clear straight road by way of experiment. He was a lone pioneer, however, and his way became lost in the centuries that followed. Nevertheless, it was his way that was followed by Galileo when once again the effort was made to get back on to the way with the firm foundation.

CHAPTER VI

Through the Dark Ages

So far we have only covered a comparatively short period of about five hundred years since the time of Thales, when Science, or the pursuit of knowledge for its own sake, might really be said to have begun. The great men we have talked about followed quickly, one after the other, and there were very many more whom we have not mentioned. Now we come to a long period of darkness and silence in the history of Science—when the path gets almost lost in a wilderness of superstition and quackery. This period lasts for about fifteen hundred years, during which no one man stands out as worthy to take his place beside the great 'seekers after truth' of the Greek era. Yet, if we probe the darkness and the silence of those long years we can follow the faint track whose beginning was carved out so boldly in Athens and Alexandria, winding tortuously through the wilderness and the gloom until at last it emerges suddenly into a burst of light and brilliance in the sixteenth century and becomes the great high road which leads directly to our own twentieth-century world of scientific wonders.

The conquest of Syracuse, in which Archimedes met his death, was one of the early stages in the conquest of the Greek empire by the Romans. Alexandria continued under the latter to be the centre of learning, but the first brilliance which was attained under the Ptolemies was never regained; and except for the Egyptian Ptolemy,

the astronomer and geographer in the second century, no science of any moment flourished there.

The Romans themselves had no love for science. They adopted the mathematics of the Greeks and applied it very successfully to engineering and architecture, and the fruits of this application are to be seen to-day in many Roman remains, especially in some of their very wonderful aqueducts for carrying water to their towns. But their engineers and scientists were always servants and very often slaves, and no honour was accorded to them. Small wonder, therefore, that science did not thrive.

The Roman Republic merged into the dissolute and decadent Roman Empire which, under Constantine the Great, became nominally Christian. In the struggle which had been waging between Christianity and Paganism the former now had the support of power and authority, and a time of terrible destruction of all things pagan began. It was at the command of one of the early Christian Emperors that a great part of the Museum Library at Alexandria was destroyed.

Even in Alexandria itself, though it was still nominally a centre of Greek learning, the old spirit had entirely disappeared. It was at this time that we find the first beginnings of Black Magic and all its attendant evils and superstitions which, in the centuries that followed, spread everywhere throughout Europe and Arabia. What we are chiefly concerned with here is the birth of Alchemy or the art of making gold.

The Egyptians, you will remember, were well skilled in metal work of all kinds. It was a common practice with them to colour, by their arts, many of the so-called baser metals so that they looked like gold. During the third century A.D. there arose a cult of people known as

the Alchemists, who claimed, with the help of certain Egyptian gods, to be able to turn these base metals into real gold. The word 'Alchemy' means really the Black Art. Whether this meant the hidden art because of its secret nature, or whether it meant the art of the black country because of the black mud surrounding the Nile after flooding, is not clear. The cult was probably originally limited to the Egyptian priesthood, but very soon certain Greeks of Alexandria were admitted. It was owing to these Greeks that Alchemy ever laid claim to be called a Science.

At this time the writings of Plato were revered above all others, and these early Greek alchemists sought and found, as they thought, justification in them for the claim that metals could be turned into gold. Plato, like Aristotle, had taught that matter was of four kinds—earth, water, air, and fire—but he had believed that it was possible to turn one kind into another.

We really do not know very much about these early alchemists, because we have very few of their writings; and those we have are so full of magic and superstition and secret signs and symbols that it is almost impossible to understand what they are about. One reason why we have so few of their writings is that one of the Roman Emperors became so frightened that a lot of gold might really be made which would not belong to him that he ordered all books which had anything to do with Alchemy to be destroyed. In this way still more of the library at Alexandria perished.

In the fourth century A.D. the Roman Empire was divided into two—an Eastern Empire with its centre at Byzantium or Constantinople, and a Western Empire still centred in Italy. Although the descent of the

Teutonic barbarians on Italy destroyed the Western Empire, the Eastern Empire continued to exist. As this included Alexandria and Greece itself, the old manuscripts, or at any rate copies of them, were kept more or less safely, chiefly in Byzantium. This city, however, became entirely cut off from the rest of Europe until the time of the crusades, and all trace of Greek culture disappeared for the time in Western Europe.

Meanwhile, however, another channel was being prepared through which these Greek writings should eventually reach Western Europe. We saw that Alexandria at one time was the centre of learning for the whole of the civilised world. Syrian and Hebrew scholars came there also to partake of the Greek store of wisdom. As a result of one of the many quarrels among the sections of the early Christian Church, a great number of these Syrians were expelled from the Eastern Empire where they had settled and become Christian, and were forced to return east to their own land. With them they took copies of the precious Greek manuscripts which they set about translating into their own language, Syriac. In this way the culture of Alexandria was preserved in this eastern land.

During the seventh century the foundations of the Arabian Empire of Islam were laid by Mohammed; and within a hundred years of his death the Arabs had conquered the whole of Persia, Asia Minor, the North-East of Africa, and were spreading into Spain. Although a warlike race, the Arabs had a very great respect for the learning of the Syrians whom they conquered. The latter were given posts as physicians, astrologers, and alchemists throughout the Empire. In the time of the great Caliphs, great centres of learning and culture were

established, where the Syrian manuscripts were translated into Arabic. Such centres were to be found at Basra, at Baghdad of Arabian Nights' fame, and at Cordova in Spain. Here, during the Middle Ages, came Europeans to study, and so the old learning of the Greeks, now interfused with later Arabic culture, returned once more to Europe.

Arabian Science.—It is probable that the Arabs added little new to the knowledge of the Alexandrian alchemists, but as our chief knowledge of the latter is from Arabian writings it is not easy to be sure on the matter. The pursuit of all the alchemists was, by this time, the search for the 'Philosopher's Stone,' that substance which should turn all metals into gold. In this search it was inevitable that a fairly extensive knowledge of common substances and their properties should have been gained and various methods of preparing them invented. All the common chemical processes, such as distillation, evaporation, crystallisation, etc., were known in those days, though the vessels used were not like our modern chemical apparatus of to-day. The only method of heating was on an open fire, and a great many of their vessels were made of fireclay and earthenware, although glass was used to a certain extent. These vessels were sealed or 'luted' with clay, for corks and rubber tubing were unknown.

The Arabs were amazingly clever workmen, and produced wonders in metal work of all sorts; in dyed fabrics; and in glass and pottery ware. There are many stories of the Moors in Spain, in which are to be found descriptions of the magnificence and splendour amid which they lived. Another very interesting thing we hear about them is that they were the first to introduce the use of

paper into Europe. This came to them from China by way of Central Asia and Arabia. When paper was in use the way was open for the invention of printing and the use of books.

The Arabs studied the science of light and were probably the first to make lenses—a very useful art, as Galileo found! They built observatories for studying the stars and constructed many astronomical instruments of types which are still in use to-day. In mathematics they added little to the geometry beloved of the Greeks; but they produced the system of Arabic numericals (1, 2, 3, 4, etc., instead of the Roman I, II, III, IV), which we use to-day. The invention of algebra is almost wholly Arabic; and the development of trigonometry must also be attributed to this people. In medicine they made great advances.

While the Arabs were amassing and storing this immense amount of detailed practical knowledge, Western Europe was gradually settling down after the Dark Ages, and kingdoms roughly corresponding to our modern national divisions were growing up. The most important thing to notice is the growth of the power of the Popes at the head of the now universal Church of Europe. Most of these early Popes were very autocratic and very jealous of any influence in men's lives other than that of their own. Thus there came to be only one authority in Europe, the authority of the Church; and the word of the Pope, through his priests, was obeyed unquestioningly. The common man was allowed to have no intelligence or mind of his own; and any attempt at freedom of thought, either religious or otherwise, was stamped out with cruelty and intolerance.

Next we must turn to notice the growth of the monas-

PLATE III

Copernicus

Leonardo da Vinci

Plate IV

Tycho Brahé in his Observatory

Note the use of the quadrant and the slit (top left-hand corner) to measure the altitude of a star This gave a much more accurate measurement than any previously obtained by similar methods

teries and of the mediæval universities. Here the only learning sanctioned by the Pope flourished, and here gradually grew up that narrow and bigoted tradition with which Galileo was to clash so violently. The first monasteries were founded at the end of the fifth century, and the monastic movement spread rapidly during the seventh and eighth centuries. They were, of course, great centres of light and learning during those very turbulent times; and the growth of education in Europe, and the multiplication and storing of manuscripts, was due entirely to them. At first the Church had little literature of its own, and it was forced to depend on old Latin manuscripts of Roman writers. During the tenth and eleventh centuries Arabic translations of the old Greek manuscripts found their way into Europe and were translated into Latin—the language of the Church. These had been translated already into two different languages—Syriac and Arabian—and as no translations are perfect, and mistakes in copying easily made, it is not to be wondered at that these Latin translations were often very different from the original. The manuscripts contained chiefly the teachings of Plato, as interpreted by later writers, and were mainly concerned with Alchemy.

In the twelfth century the Crusades brought about the first contact between Eastern and Western Europe for many a long year. Palestine was reached by way of Byzantium, where some of the more educated Crusaders were attracted by the Greek manuscripts which they found there. It was in this way that many of the writings of Aristotle reached Europe and engaged the attention of a learned monk named Thomas Aquinas. He translated these manuscripts into Latin and made a very careful study of them. He came to the conclusion that the

teachings of that famous old Greek were fully in accordance with the Roman Catholic doctrine. So Aristotle received papal sanction. His writings were studied and copied with such enthusiasm in all the monasteries and universities that, within a comparatively short period, to disagree with his teachings was heresy in the eyes of the Church and punishable by fire.

During the centuries that followed, the works of Aristotle formed the central study at all the universities throughout Europe, and that part of Aristotle's teachings that these mediæval professors and students learnt better than anything else was to argue in a strictly logical manner. To them, a learned argument came to be the most convincing of all things—far more convincing than anything they saw or heard for themselves; and in the great battle fought in the sixteenth century this was the weapon which the opponents of the new science brought with such confidence to the fray.

Alchemy.—It is hardly surprising that, with the minds of men turned so firmly towards the past, little advance was made in science during those years. After all, Aristotle had written an amazing amount about the natural world, and that amply sufficed for these old scholars. The chief science, so called, of that time was the ancient art of Alchemy which came to Europe from the Arabs. Attached to the court of almost every noble was an alchemist, who, as a rule, practised also astrology and magic. He advised his lord as to auspicious occasions on which to carry out his activities. The idea of having untold wealth at his command naturally inflamed the imagination of each nobleman. Many a fraudulent experiment was staged to convince him that the secret had been gained and so assure continued favour for the alchemist.

Nevertheless, the majority of the really intelligent men of the day honestly believed that transmutation into gold was a real possibility if only the philosopher's stone could be made. Their justification for the belief was to be found in the views which they held concerning the nature of matter, which views they derived from Aristotle. Let us remind ourselves what they were:

> Anything which occupied space consisted of matter of some sort.
>
> There were four different kinds of matter, called the elements; these were earth, water, air, and fire.
>
> Solids consisted chiefly of the element earth, but often contained smaller amounts of the other elements which could generally be driven off by heat.
>
> Liquids consisted chiefly of the element water.

By sufficiently altering the properties of a substance—as, for example, its appearance and texture—it was possible to turn it into something else. This is what Aristotle taught.

In addition, the alchemists of the Middle Ages held certain ideas as to how the metals came to be formed. These had come down to them from the Arabs. From the four elements present in the earth, the first compound substances to be formed were mercury and sulphur. These two mixed together beneath the surface of the earth and under the influence of great heat and during the lapse of a considerable period of time formed the metals. If the conditions were quite perfect and the heavenly bodies in favourable positions with reference to one another, then gold, the perfect metal, was formed. If not quite enough time was taken over the process, then not gold but silver was the product; while if any, or all, of the

other conditions were wrong, then either copper, tin, iron, or lead were formed instead.

According to these ideas, therefore, the base metals were thought to be just impure gold, or gold gone wrong in the making; and so it should not be so difficult to alter those qualities which were wrong, such as colour, hardness, etc., and get gold in the end. Needless to say, the mediæval alchemists were no more successful than their predecessors; but all the time they were improving their methods of working; and from time to time new substances were discovered. Many of these are the common reagents of our chemical laboratories to-day, although they were then called by quite other names. For instance, what we call nitric acid they called aqua fortis (strong water), because it would dissolve so many metals; while aqua regia, which is a mixture of nitric and hydrochloric acids, was so called because it alone would dissolve that king of metals, gold. They also discovered what they called spirits of salts (hydrochloric acid), spirits of hartshorn (ammonia), and many others. Nevertheless, in spite of such discoveries, no real advance was made in understanding the nature of the materials they used and the reason for their various reactions upon each other. It was not until the seventeenth century that chemistry as an ordered science came into being.

Paracelsus (1493–1541).—Before that, however, the search for new substances was widened considerably owing to a man commonly known as Paracelsus (his real name was Theophrastus Bombastus von Hohenheim!). He was a Swiss physician who lived in the sixteenth century—very much later than the times we have been talking about, but still before the birth of modern chemistry. He taught that a great deal of talent and energy was being

wasted in this search for the philosopher's stone. These, he said, should be turned instead to the study of substances with a view to their use as medicines, and especially should search be made for that substance, the Elixir of Life, which should prolong life indefinitely.

Paracelsus fell out very badly with the rest of his profession because he publicly burnt all his books written by Galen and Avicenna, the two great authorities on medicine; and said that, henceforth, he would rely only on his own powers of observation and his experience gained by the use of his medicines.

He had some very curious ideas as to how our bodies function, but these do not concern us here. He also produced a new theory as to the composition of matter, substituting for Aristotle's four elements the three 'principles' of sulphur, mercury, and salt. The part of a substance which would burn contained the principle of sulphur; that which would volatilise or turn into vapour when heated contained the principle of mercury; while the solid which remained when all the sulphur and mercury had been driven off contained the salt.

By this time, you see, the yoke of Aristotle had been lifted somewhat and new ideas were being produced. It cannot be said, however, that the new theory of Paracelsus was a great improvement. What is to his credit, however, is the impetus which he gave to the search for new chemical substances.

This, then, is the story of Alchemy up to the middle of the seventeenth century, and to make it complete we have really gone too far ahead in time. Now we must go back again to the thirteenth century and hear about one man who realised what shackles bound men to the past and had a vision of what true science ought to be.

Roger Bacon (1214–1294).—This man was Roger Bacon, an Englishman. Because of his new way of looking at things he has been called 'the Herald of the Dawn.' Like all the educated men of that time, he was a monk; but he was a very unorthodox monk and frequently in hot water because of his outspokenness. He claimed that the true way to acquire knowledge was by experiment and not by argument; and that authority (for example, what Aristotle said) carried no weight if experiment said otherwise. He lived up to his teaching by carrying out a great many experiments; and he made a number of new and valuable discoveries, more especially in connection with Light. He was an alchemist as well, and believed in the possibility of transmutation. He wrote down the results of his experiments, together with his ideas on how science should be studied, in three books which he called *Opus Maius* and *Opus Minus* and *Opus Tertium.* As you might expect, these books were not at all popular with the authorities, and he was put into prison for writing them. He was kept there for fourteen years, and was only released, to die almost at once, in his eightieth year.

Leonardo da Vinci (1452–1519).—After Roger Bacon came another period of three hundred years when no name stands out as worthy of mention, except that of Leonardo da Vinci. This great Italian lived about two hundred years after Roger Bacon, and a hundred years before Galileo. Leonardo da Vinci is, perhaps, best known as a painter; he painted the famous picture of the 'Last Supper' and also the portrait known as 'Mona Lisa,' both of which are considered to be amongst the world's greatest pictures. Only comparatively recently has it been realised that his genius was by no means limited to painting or any form of art. He had a passion

for knowing the truth about things, and his notebooks are full of drawings and notes on every conceivable subject, from designs for flying-machines to the habits of poisonous spiders. He loved mathematics, and by its aid designed a great variety of machines, many of which were used by his patron, the Duke of Milan. He scorned the alchemists in their search after gold, and fully realised the impossibility of transmutation. His notebooks show that he discovered many things which did not become generally known until their rediscovery by others much later. One writer about Leonardo has said that if Galileo is called the 'Father of Experimental Science,' then Leonardo da Vinci might be called its grandfather!

Certainly both Roger Bacon and Leonardo da Vinci broke away from the darkness and reached the light—but the rest of their fellows were not ready to follow them. So no permanent way was yet made.

CHAPTER VII

The Dawn of a New Age

THE man who actually ushered in the new age of science was *Nicholas Copernicus*. He was born in 1473 at Thorn, in Poland, on the River Vistula. His great contribution to Science was his conclusion, arrived at after a lifetime of careful observation of the heavens, that it was the earth which moved round the sun and not the sun round the earth, as all the world then believed because of the teachings of Aristotle and Ptolemy.

Copernicus first went to the University of Cracow with the object of becoming a doctor. He soon found, however, that he was far more interested in mathematics and astronomy than in medicine. After qualifying to be a doctor he devoted himself to the study of these two other subjects, and before very long he became Professor of Mathematics at Rome. He did not stay long at Rome, however, but, being appointed a canon in the cathedral of Frauenburg, he returned to his own country. Here it was that he spent the rest of his life and carried out that wonderfully exact series of observations which finally led him to his famous decision as to the true state of affairs among the heavenly bodies.

Let us see how he carried out these observations. Remember that the telescope was not yet invented, nor many of the other great instruments of our modern observatories. First we must understand just what it was that he had to do. Imagine a great circle passing through the North and South Poles and the point

immediately overhead (the zenith). This circle is called the meridian. The sun crosses the plane of this circle every day at noon, and at some time during the twenty-four hours every star crosses it. The time at which each star does this is a very important determination in astronomy. To carry out these determinations, he

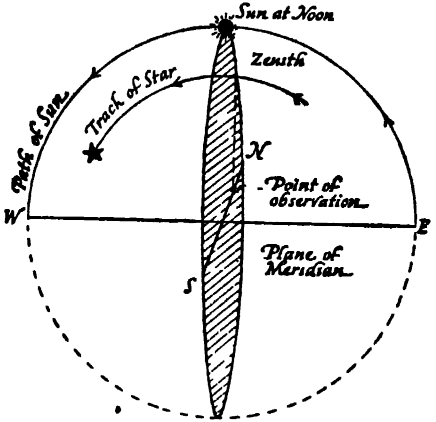

FIG. 4.—The meridian. The shaded area indicates the plane of the meridian, at right angles to the plane of the paper

arranged slits in the walls of his house so that he could note the 'transit' of the stars across the meridian. He also made himself an instrument called a quadrant, by which he could measure the altitude of each star as it passed.

Copernicus studied especially the movements of the planets, and it was this study which led him to his famous conclusion. Now it is most important that you should not think that it was quite a new idea to Copernicus that the earth should move and the sun stay still. He was a very well-educated man and definitely tried to read as

many as he could of the writings of the ancient Greeks about their ideas of the universe. Thus he knew very well that although Aristotle had taught that the earth was still, Pythagoras had said that it, and the planets, moved round a central fire; while a later astronomer, Aristarchus, had actually taught that the sun was the centre round which the earth and the planets moved.

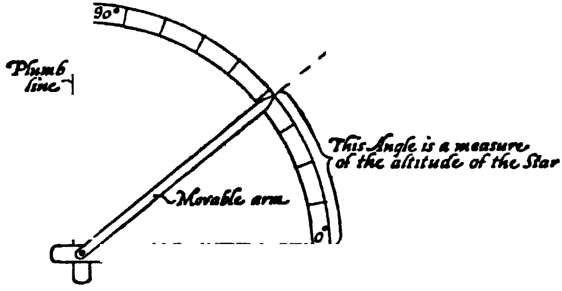

FIG. 5.—A simple quadrant

What Copernicus did, therefore, was to show that the motions of the planets, as he had observed them, were explained more simply by the theory of Aristarchus than by that of Aristotle and Ptolemy.

Copernicus was a very modest and retiring man and was not at all anxious to make his views known, but his friends finally persuaded him to publish them. This he did in the famous book called *De Revolutionibus Orbium Cœlestium.* This, however, was not until he was an old man, and before it was published he was smitten with a paralytic stroke, and it was only a few hours before his

death in 1543 that the first copy of the book was put into his hands.

Now, although Copernicus was a canon of the Church he realised that his book would be extremely unpopular. Nevertheless he dedicated the book to the Pope, and expressed his conviction that the ideas which it contained were not contrary to the truest and best teachings of his Church.

At first the Pope was immensely pleased by the dedication; but when once the contents of the book were fully understood, it called forth quantities of abuse, and any man proclaiming himself to be a convert to the Copernican view suffered great disrepute. Indeed, a certain man named Giordano Bruno was imprisoned for six years and finally burnt at the stake.

Before we come to Galileo, who was the greatest of all the supporters of this theory, there are two men whose joint work was tremendously important to the progress of the new astronomy. The first of these, Tycho Brahé, was never a convert to the Copernican theory, while the second, Kepler, was its keen supporter from the first.

Tycho Brahé.—Tycho Brahé was a Dane of very good birth. At that time it was not at all usual for well-born people to receive a good education, but luckily Tycho Brahé had an uncle who was himself well educated, and he adopted this nephew and sent him to the University at Copenhagen. He was really meant to study law, but the occurrence of an eclipse which had been predicted so fired his interest in astronomy that he decided to devote his life to its study.

From the first, his real interest lay in making observations of the heavenly bodies rather than in inventing theories to account for their movements. This was just

as well, as the one theory he did put forward was not at all a brilliant one. On the whole, he was a fairly steady supporter of Ptolemy's system all his life.

Tycho Brahé was at once struck with the inaccuracy of all the observations of the stars which had been made hitherto, even those of Copernicus. He therefore set about making much larger and more elaborate instruments, and by their aid was able to carry out observations far exceeding in accuracy any which had previously been made. This accuracy was due not only to the superiority of his instruments but also to the skill and care of Tycho Brahé himself.

The King of Denmark was greatly impressed by his ability, and seemed to have realised that every help and encouragement should be given to a man of his eminence. He therefore gave him an island and £20,000 with which to build an observatory. This observatory, which was called Uranienburg (the castle of the heavens), was a wonderful affair when it was built. It was fitted with laboratories and workshops, and in the actual observatories with the most splendid instruments that Tycho Brahé had so far made. Here for the next twenty years he gradually accumulated the most complete and accurate set of observations on the heavenly bodies that had ever existed. He won great renown as a man of Science, and was visited by eminent personages from all over Europe.

Unfortunately, when his patron the King of Denmark died, he lost favour with the new king and had to abandon his wonderful castle. After two years of wandering in Europe he was invited by the Emperor of Bohemia, Rudolph II, to settle in Prague, and was given a castle, to which he was able to bring his instruments. Once more students flocked to him, and an important piece

of work was begun which he called the Rudolphine Tables—astronomical tables intended for the use of navigators. But the anxiety and privations of the last years had so told on Tycho Brahé that he soon fell ill and died in 1601, committing to Kepler, on his death-bed, the work of completing the Rudolphine Tables.

Kepler.—Johann Kepler was born in very different circumstances from Tycho Brahé. His mother was low-born and bad tempered, and his father continually in money troubles. When four years old Kepler suffered from smallpox, which left him with impaired eyesight and an unsteady hand. At ten years old he was taken from school and served as a pot-boy in a tavern which his father was keeping at the time. Later, however, he was able to attend a monastic school and finally managed to get to the University of Tübingen. Here the professor of mathematics soon detected Kepler's genius and at once introduced him to the doctrine of Copernicus to which he himself was an acknowledged convert. Kepler became a powerful defender of this doctrine and soon established a considerable reputation. At twenty-three years of age he was offered a professorship in Astronomy at the University of Graz, which he accepted for the time being, but determined to look out for something better, as the salary was not at all good and he was tired of continual poverty.

The question which most of all interested Kepler was whether there was a definite scheme governing the movement of the planets. There were still only six planets known—Mercury, Venus, the Earth, Mars, Jupiter, and Saturn; and of course it was only people who believed in the Copernican theory who thought of the Earth as a planet. Kepler also knew that Saturn was the farthest